Gasification of biomass for gas reburning in close-coupled boiler applications

R.B. Williams[a], B.C. Meister[a,b], L. Fernando-Calvo[a,c], B.M. Jenkins[a,*] and P.H. Heyerdahl[a,d]
[a]Department of Biological and Agricultural Engineering, University of California, 1 Shields Avenue, Davis, California, USA 95616-5294
Fax: 530-752-2640; bmjenkins@ucdavis.edu
[b]also California Energy Commission; [c]visiting from University of Leon, Spain; [d]on sabbatical leave from Agricultural University of Norway

Fuel reburning and advanced reburning techniques are used to reduce NOx emissions from boilers. Reburning in some biomass fueled boilers is already practiced using natural gas as the reburning fuel. Gasification of biomass offers another means of implementing reburning in NOx control strategies for biomass fueled Rankine cycle power plants and similar concepts [1]. Siting the gasifier directly adjacent to the boiler in a close-coupled mode eliminates any need for gas cleaning prior to firing the product gas to the boiler. The close-coupled gasifier also allows fuels that are difficult to burn directly in the boiler to be used for power generation where they might not otherwise be used. High fouling and slagging fuels, such as cereal straws, other agricultural biomass, sludges, and a number of other materials, can be fired to the gasifier rather than directly to the boiler. The gasifier, operating at lower temperature and with a different reaction environment, can be employed to control the concentrations of alkali and other undesirable elements entering the boiler. The product gas from the gasifier is generally more readily fired to the boiler than are solid fuels. Ammonia in the producer gas and small amounts of alkali carrying over with the gas may promote the reburning reactions and increase the destruction of NOx.

The feasibility is currently being investigated of close-coupled gasifier systems using selected biomass fuels for reburning in both exisiting and new biomass power plants. The project incorporates investigations of resource distribution and availability for fuel selection, bench-scale fluidized bed gasification experiments, char reactivity studies, pilot-scale gasifier and boiler tests, modeling, and economic analyses intended to lead to full-scale demonstration. Reported here are results obtained from bench-scale fluidized bed gasification experiments for agricultural biomass including almond shells and rice straw. Other fuels including various woods and a municipal digester sludge are also to be tested.

Experiments were conducted in a 75 mm i.d. laboratory fluidized bed reactor. A disengagement zone situated at the top of the main reactor column expands the flow and is used to internally recirculate bed grains and larger fuel particles. The reactor wall temperature is controlled by a surrounding external electric furnace. Primary fluidizing air can be preheated prior to reaching the air distribution nozzles located at the bottom of the reactor. Fuel is metered through a variable speed belt conveyor discharging onto a high-speed injection screw feeding into the bottom of the bed. Fuel is milled to 1 mm nominal particle size before feeding. An alumina-silicate bed grain (Ione Investocast 60 or 35, North American Refractories Company) is normally employed for the experiments, but the type of grain is varied depending on the fuel composition and agglomerating characteristics. Products exiting the disengagement zone pass through a deposit test section and cyclone particle separator before being flared off. Spent bed and flyash are collected for analysis after each test. Samples are extracted from the cyclone stack for major gas, ammonia, tar, and alkali metal concentrations, the latter via a heated filter to separate gas phase and particle phase alkali.

Rice straw constitutes the most difficult fuel from a bed agglomeration perspective, but represents a fuel of considerable interest for power generation in California due to its concentrated production in the Sacramento Valley, the potential air quality benefits resulting from a reduction in open field burning, and the exisitence of a number of biomass fueled power plants in the immediate region, including circulating fluidized bed, suspension, and stoker-fired traveling grate combustors. None are capable of burning rice straw due to its high slagging and fouling characteristics and because the boilers were not designed to handle straw unless first leached to remove potassium and chloride [2, 3].

Fresh, unleached rice straw was gasified in the laboratory unit using two types of bed material. All experiments using the normal alumina-silicate grain failed after a short period of time due to agglomeration of the bed at temperatures as low as 700°C with air-factors of 0.1 to 0.3. Agglomeration was avoided at bed temperatures up to 800°C when using a magnesium oxide bed. Gas quality was in all cases marginal with a higher heating value of 3 MJ m^{-3} and low H_2 concentration. Attrition rate was high for the magnesium oxide. Other experiments are being conducted on magnesium oxide blending to reduce consumption.

A high ash, high nitrogen almond shell fuel was gasified successfully using the standard bed grain when operating at bed temperatures up to 750°C and 0.2 air-factor. Gas quality was good with a higher heating value of 6.4 MJ m^{-3}. Ammonia concentration in the dry gas was 0.47%. The value is in the range of concentrations reported by Ishimura, et al. [4], who noted that increasing gasification temperature produces a large decrease in NH_3 between 700 and 830°C. Turn, et al. [5] reported ammonia concentrations up to 0.17% for banagrass gasification, and determined that ammonia in the gas increased linearly with fuel nitrogen concentration for bed temperature held constant at 800°C.

Although the bed did not defluidize due to agglomeration when firing almond shell, small, lightly sintered agglomerates were found when the bed was dumped after the runs. Larger agglomerates collected on the reactor wall around the discharge end of the fuel feed tube, and sintered deposits appeared on the reactor wall in the freeboard above the expanded bed where wall temperature is highest. These did not interfere with the operation, but longer duration runs may suffer from agglomerate build-up and increasing particle size in the bed.

Results from these experiments and predictive modeling are used in the design of the pilot scale experiments. Results will also be used in predicting potential NOx reductions due to reburning in the coupled boiler.

References:

1. Zamansky, V.M., B.M. Jenkins, T.R. Miles and V.M. Tiangco. 1999. Hybrid combustion-gasification approach for environmentally safe utilization of biomass energy. In: Overend, R.P. and E. Chornet (eds.), Biomass: a growth opportunity in green energy and value-added products. Pergamon, Oxford, pp 1335-1340.
2. Jenkins, B.M., R.R. Bakker and J.B. Wei. 1996. Biomass and Bioenergy 10(4):177-200.
3. Jenkins, B.M., R.B. Williams, R.R. Bakker, S. Blunk, D.E. Yomogida, W. Carlson, J. Duffy, R. Bates, K. Stucki and V. Tiangco. Combustion of leached rice straw for power generation. In: Overend, R.P. and E. Chornet (eds.), Biomass: a growth opportunity in green energy and value-added products. Pergamon, Oxford, pp 1357-1363.
4. Ishimura, D.M., 1994. Investigation of Nitrogenous Compound Formation in Biomass Gasificataion. Master of Science Thesis, Department of Mechanical Engineering, University of Hawaii.
5. Turn, S.Q., C.M. Kinoshita, D.M. Ishimura and J. Zhou. 1998. Fuel 77(3):135-146.